THE STRATIGRAPHIC DISTRIBUTION OF THE EDIACARA FAUNA IN AUSTRALIA

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ABSTRACT

The uppermost Precambrian Ediacara fauna has been found in almost continuous outcrops along the west flank of the Flinders Ranges, from near Hawker to Mt. Scott Range 140 km north. All occurrences are stratigraphically low in the upper member of the Pound Quartzite. In parts of this region erosion prior to deposition of the Parachilna Formation has removed 500 m or more of the upper member; the entire upper member was eroded prior to the deposition of the Parachilna Formation or the Lower Cambrian Wilkawillina Limestone, in the ranges on the east flank. Trace fossils, *Plagiogmus* and probable *Rusophycus*, indicate a lowest Cambrian age for the Parachilna Formation which is overlain by the Wilkawillina Limestone or its equivalent the Ajax Limestone.

INTRODUCTION

The rich Precambrian fauna discovered near the top of the Pound Quartzite at Ediacara Range by Sprigg (1947, 1949) was augmented by the collections of Mincham and Flounders (Glaessner, 1955 *et seq.*) and later workers. These discoveries and the failure to find fossils at other levels in the Precambrian at Ediacara triggered fruitless searches concentrated on the top of this formation elsewhere. Only in the area of outcrop closest to Ediacara Range, Red Range, Beltana, was a small fossiliferous outcrop revealed; this was 180 m below the top of the Pound Quartzite, a much greater distance than at Ediacara, and in a much thicker sequence. The stratigraphic relationships of these two isolated areas remained uncertain.

The study of the preservation of the soft bodied fauna (Wade, 1968) brought out the fact that requirements for preservation were not particularly stringent. The fauna could be preserved anywhere that sediments which had finally been deposited without reworking could be found. Such an environment was ascribed to the Ediacara Range deposit on independent sedimentary evidence by Goldring and Curnow (1967). The conditions required for the exposure of fossils were either that the rocks were naturally flaggy, or that the fossils were sufficiently tough and large to cause a weakness in a massive rock where sand-grains had been prevented from interlocking, so that the rock parted along the site of the fossil during weathering. Accordingly a new investigation was launched, which concentrated on finding suitable beds. It was immediately successful.

The present paper records the stratigraphic position and distribution of the Ediacara fauna within the area shown in Fig. 2. Fig. 2 shows the outcrop of the Pound Quartzite in the area outlined in Fig. 1 and indicates the 22 sections examined in the course of this work. Areas not yet examined include the thickest development of the Pound Quartzite, the northeast of the Northern Flinders Ranges.

PREVIOUS WORK

Reference to the Pound Quartzite is found in many of the works of Mawson who measured sections at Italowie Gorge and Campbell's Bald Hill Range (Mawson, 1937), defined the formation (Mawson, 1938), gave the earliest description of the two members into which the formation is still informally divided (Mawson, 1941), and preliminarily mapped most of the Central Flinders Ranges

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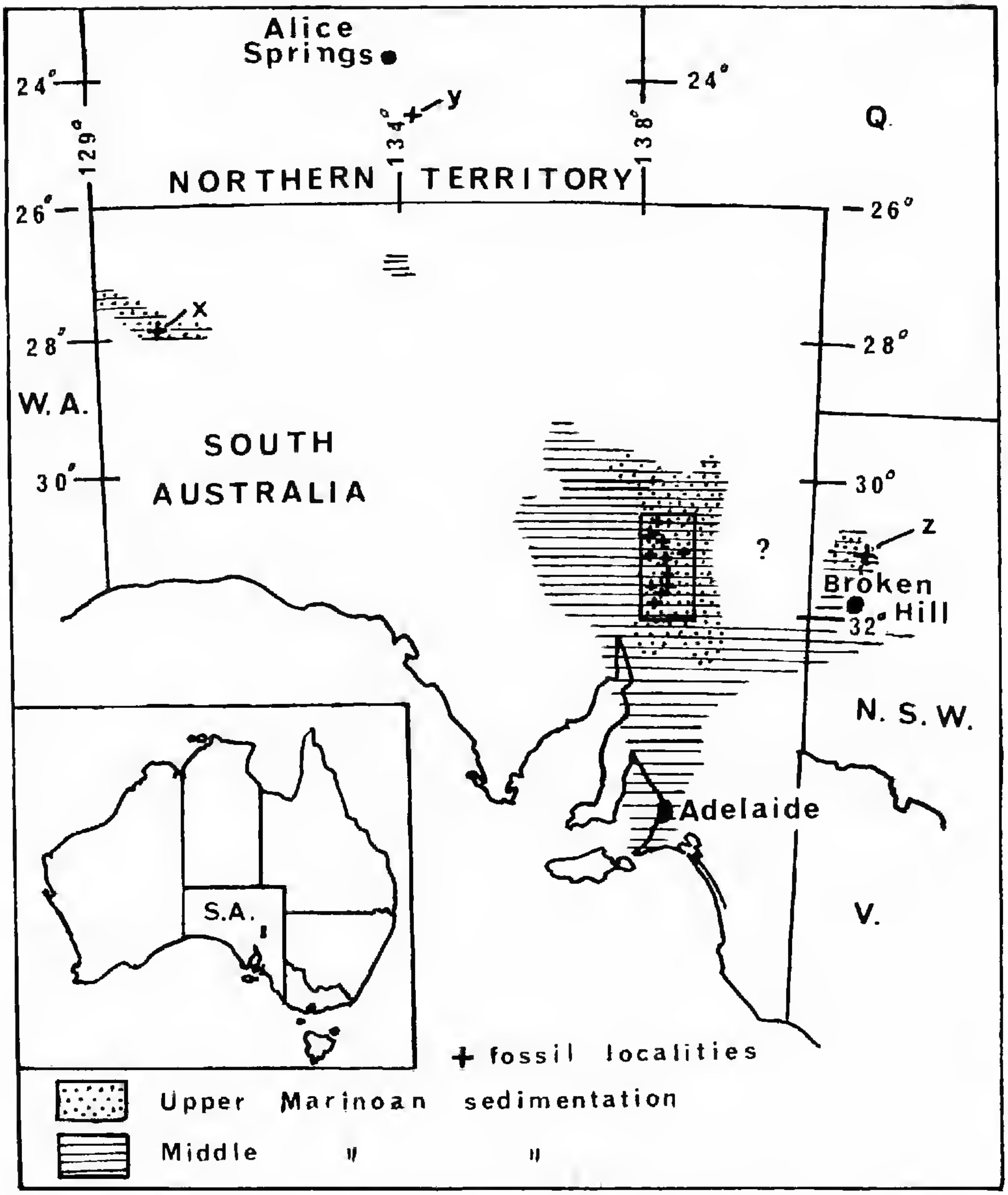

Fig. 1. Areas of Late Precambrian sedimentation showing localities where fossils of the Ediacara fauna have been discovered. Boxed area, within the Flinders Ranges, see Fig. 2; "x" Punkerri Hills; "y" a few km E of Deep Well Homestead SSE of Alice Springs; "z" Fowlers Gap Beds underlying Lintiss Vale Beds a few km NW of Acacia Downs Homestead, NNE of Broken Hill. (Mainly after Thomson, 1969a, and Webby, 1970.)

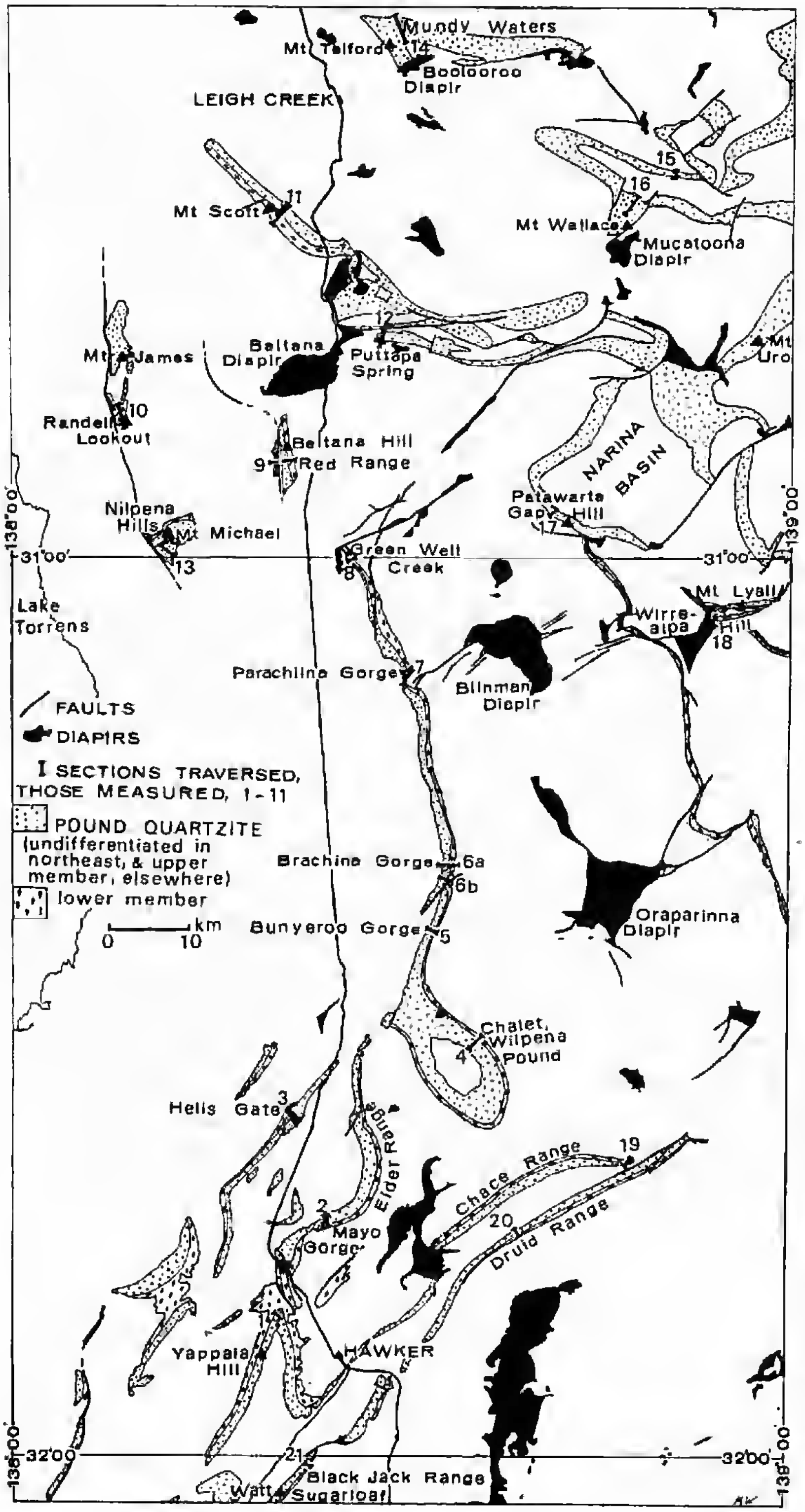

Fig. 2.
Outcrop of Pound Quartzite showing sections searched for fossils: fossils *in situ* have been obtained from 1-3, 5-11; definitely fossiliferous float from 13 and 17, Nilpena Hills and Patawarta Gap, and probably fossiliferous float from Puttapa Spring, 12. Diapirs within the area are shown in black.

(Mawson, 1942). Additional references may be found in Teesdale-Smith (1959). There is considerable difficulty in reconciling some of the thicknesses obtained in this early work with later data. Campana (1958) provided a number of structural sections across the Northern Flinders Ranges but omitted the thicknesses of beds. Thicknesses are provided by Thomson (1969b) in interesting diagrams of the facies relationships but the diagrams are of too small a scale to allow precise geographic location, or to show structure.

Modern stratigraphic work at Ediacara commenced with Glaessner and Daily (1959) and was continued by Nixon (1963), and by Goldring and Curnow (1967) on the sediments. Goldring and Curnow convincingly demonstrated an unconformity between the Pound Quartzite and the overlying Parachilna Formation at Ediacara Range, though their paper was not cited by Leeson (1970) who adhered to the view that there was no significant break and Segnit's report (1939) of a disconformity in this position was wrong. Meanwhile Dalgarno (1962, 1964) and Dalgarno and Johnson (1962, 1964) in defining and discussing the Parachilna Formation in the main Flinders Ranges had already shown a regional unconformity in the same position, which may be equated with that at Ediacara.

The first large-scale attempt to systematize the description and naming of beds in the Adelaide Geosyncline was carried out by Daily (1956) on the Cambrian. Thomson *et al.* (1964) similarly established a regional nomenclature for the Precambrian. The most recent review is that of Thomson (1969b).

Since the 1950's the South Australian Geological Survey has been issuing maps of parts of the relevant area on the 1:63,360 scale. More recently this data and that gathered by later work has been distilled into 3 sheets of the 1:250,000 geologic map series. From S to N these are: Orroroo (Binks *et al.*, 1968), Parachilna (Dalgarno and Johnson, 1966) and Copley. The last is an unpublished preliminary version displayed in MS. The Parachilna 1:250,000 sheet was the first to record the distribution of the lower and upper members of the Pound Quartzite. This example was followed in the 1:63,360 map series but regrettably not in the Orroroo 1:250,000 sheet, nor, as yet, in the Copley sheet. Reports of investigations accompany some map sheets: Arrowie (Horwitz, 1962), Blinman Dome (special series; Coats, 1964a), Marree (Forbes, 1966), Beltana (Leeson, 1970), or concern other projects such as the hydrology of Frome Embayment (Ker, 1966) which assembled little-known subsurface data.

STRATIGRAPHY

The Pound Quartzite is the youngest formation in the Adelaide Geosyncline to which the age "Marinoan" has been applied (Thomson *et al.*, 1964; Thomson, 1969b). If it is intended that Marinoan reach to the base of the Cambrian (Thomson, 1966), however, a subsiduary type area where the rocks do not terminate in an unconformity should be sought.

All beds containing elements of the Ediacara fauna have been placed in the Upper Marinoan Epoch (Fig. 1, +). Within the Adelaide Geosyncline the beds deposited during the Marinoan have already been recognized as susceptible of a 3-fold subdivision (Thomson *et al.*, 1964; Thomson 1969b, pp. 68-79, figs. 22, 27). This subdivision appears likely to be widely applicable. The oldest or Lower Marinoan sediments are influenced by the third and last phase of Precambrian glaciation which has been used for correlation with northwest New South Wales (Webby, 1970), and is possibly correlative to the last phase of glaciation in the East Kimberleys, which is overlain by marine shales currently dated at 665 ±45 m.y. (Compston and Arriens, 1968). The Lower Marinoan sediments of the Adelaide Geosyncline are part of the Umberatana Group which also includes all

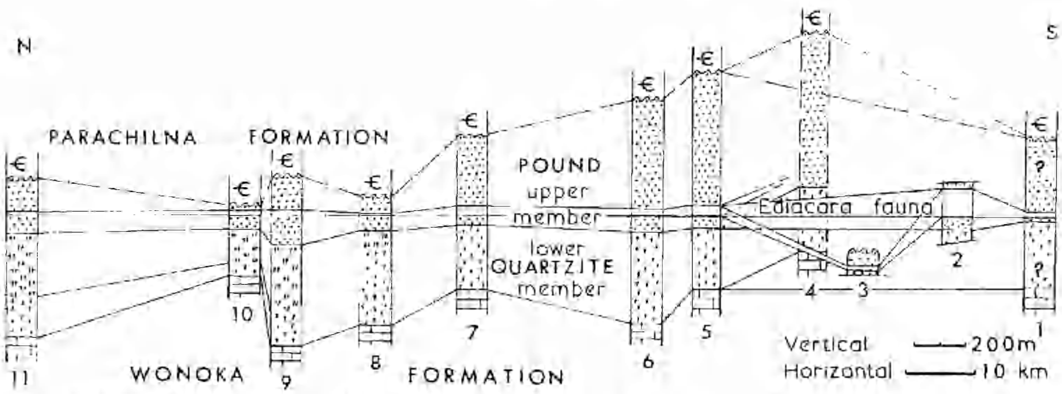

Fig. 3. Sections 1-11 as named on fig. 2. Only the central portion of section 1 was measured, the total thickness is conservative.

the Sturtian glacial and inter-glacial beds. Stromatolites are the only known fossils. The remainder of the Marinoan sediments are the Lower and Upper Wilpena Group sediments (Thomson, 1969b, fig. 27) which may be regarded respectively as Middle and Upper Marinoan. The trace fossil *Bunyerichnus dalgarnoi* Glaessner (1969) was described from the Middle Marinoan of Bunyeroo Gorge but no other fossils are known. The Upper Marinoan consists of the Bunyeroo and Wonoka Formations and the Pound Quartzite which alone has produced animal fossils. These are of such variety and size that a long history of development must lie in older sediments.

Fig. 1 shows the distribution of sediments of Middle and Upper Marinoan age (after Thomson, 1969b, fig. 27; Webby, 1970) and known fossil localities of the Upper Marinoan. The area marked "?" is the Frome Embayment of Mesozoic

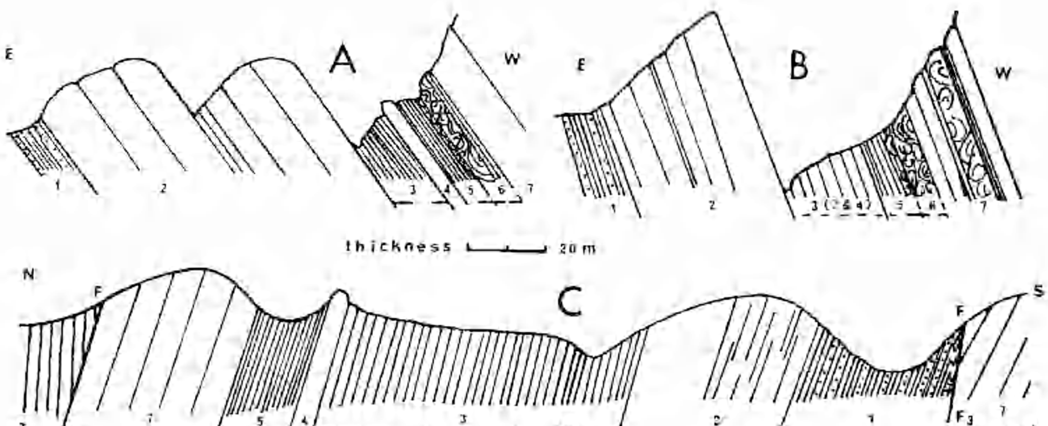

Fig. 4. Generalized sketches of the outcrop from the top of the lower member, Pound Quartzite, through the fossil beds. True dips and thicknesses are shown. A. Brachina Gorge. B. Bunyeroo Gorge. C. Mayo Gorge. 1. Top of lower member. 2. Unfossiliferous basal beds of upper member. 3. Lowest fossiliferous bed. 4. Unfossiliferous intercalation. 5. Upper fine-grained fossiliferous bed. 6. Fossiliferous, fine- to coarse-grained, white sandstones. 7. White sandstones of the cross-stratified to flat stratified facies. Slump rolls have been observed in 5-7 where diagrammatically indicated. The horizontal lines below 3, 5, 6 indicate approximately the position of fossiliferous beds.

to Recent age which is known from bore data (Ker, 1966) to be underlain by Precambrian and Cambrian rocks in N-S trending blocks, like these exposed on its east and west margins. Detail on the correlation of possible Adelaide System rocks is lacking.

The Pound Quartzite

This formation occurs between approximately 30° and 32°33′S latitude. It rims many synclinal and basinal structures in the Northern and Southern Flinders Ranges but is restricted to the flanks of the Central Flinders Ranges (Fig. 2) where uplift and deep erosion has exposed Sturtian rocks and large diapiric cores (Mawson, 1942; Coats, 1964a; Dalgarno and Johnson, 1966). Immediately prior to the deposition of the Pound Quartzite, fine-grained carbonate-rich sediments were deposited over the area. These rocks are known as the Wonoka Formation (Dalgarno and Johnson, 1964) and are usually grey to brown or red siltstones and shales with bands of limestone but occasionally dolomite or limestone predominate.

The base of the lower, or red, member of the Pound Quartzite indicates an abrupt regional change to haematitic, felspathic sandstones (Fig. 3), usually through non-calcareous, red siltstones. The member is dominantly medium- to fine-grained, with ferruginous coatings on the grains in most beds, though some included sandstones are orthoquartzitic; it contains minor amounts of clayey siltstones and a very few grits; small-scale cross-bedding is dominant but current-swept, flat bedding planes also occur; ripple-marks are common; a few bedding planes reveal a suitable lithology for the preservation of fossils but only rarely have possible trails been found. A basal conglomerate occurs south of the Beltana Diapir in Red Range (Leeson, 1970).

The upper, or white, member consists of clean, coarse to medium-grained felspathic sandstones, with rare fine sediments. For the most part beds are rather massive and cross-stratified to flat-stratified (Goldring and Curnow, 1967). Slump rolls are common in some beds, as are mudflake conglomerates, cut-and-fill scours and ripple-marks. Grit bands are rare; conglomerate bands occur adjacent to Mucatoona Diapir. For the most part reworking during deposition has removed any ferruginous coatings from grains but at a height of about 16-80 m above the base in the west flank of the Flinders Ranges, red beds are included in a substantially fine-grained deposit which extends for 145 km N-S, from the south branch of Green Well Creek to Black Jack Range, south of Hawker. A great deal of this is very fine-grained sandstone and minor siltstones and much of it is fossiliferous. The thickness of the fine-grained beds varies from 7-112 m, largely according to how much barren sandstone is interbedded. The barren sandstones may be relatively fine and even-bedded (Mayo Gorge, Bunyeroo Gorge; Figs. 3 (2,5); 4C,B); mud-pellet conglomerate, coarse sandstone, and small "slump rolls" (Brachina Gorge, Figs. 3 (6), 4A); or slump rolls up to 2-3 m thick and normal, bedded sandstones (Parachilna Gorge, Fig. 3 (7)). Evidence of slumping and/or scouring is recurrent wherever sections have been examined.

Fossils are known in almost continuous outcrops from Green Well Creek to Yappala Range just WNW of Hawker. Isolated from these almost continuous outcrops are beds with fossils at Red Range, Edicara Range and Mt. Scott Range. All these beds occur low in the upper member of the Pound Quartzite, and they are correlated as a datum plane in Fig. 3. The fine-grained sediments are almost exclusively red beds from Mt. Scott Range in the north to south of Brachina Gorge but the lower portion is whitish sandstone at Bunyeroo Gorge and south (Fig. 4, A-C).

The picture of the Pound Quartzite as an uncomplicated, two-member formation is over-simplified, though there are only minor deviations from this norm in the area of the Parachilna 1:250,000 sheet and adjacent parts of the Orroroo 1:250,000 sheet to the south. These are:

1. Intermittent orthoquartzitic sandstones in the lower member; particularly thick beds are seen at Green Well Creek on the west flank and on the east flank at Wilkawillina Gorge, near Oraparinna Diapir.
2. The fine beds near the base of the upper member on the west flank.
3. Light maroon, haematitic sandstones occurring intermittently in the upper member particularly in Yappala Range and around Parachilna Gorge.

North of 30°57′ on the west flank of the ranges, the lower sediments become more sandy between Nilpena Hills and Green Well Creek on the south, and Red Range on the north. Section 9 (Fig. 3) is based upon thicknesses measured by Major (unpublished thesis, 1964) along the creek next south of Red Range waterbore, and in a direct line east. He did not make a large-scale subdivision of the Pound Quartzite but his data suggested, and further field study has confirmed, that the section could be divided into three units on the basis of upwardly decreasing frequency of red beds. These three units were, from the base: 140 m of haematitic, felspathic sandstones lithologically characteristic of the lower member; 248 m of interbedded, haematitic and orthoquartzitic sandstones; 257 m of mainly orthoquartzitic sandstones with minor red beds. Comparison of thicknesses with section 8 (Fig. 3) served to suggest that the two lower units at Red Range, together, are equivalent to the lower member to the south, and this was confirmed by the position of the fossiliferous bed. The outcrop at Red Range is duplicated across a N-S strike fault (Leeson, in Leeson and Nixon, 1966; Leeson, 1970, figs. 3, 4) but contrary to both publications the lower member as well as the upper outcrops west of the strike fault, though its base is truncated. The fossil bed is thinner and less rich in the eastern section than in the western; only the epichnial groove Form B (Glaessner, 1969), has been recovered east of the fault, while fossils listed in Table 1 have been found in the western outcrop. There the fossils occur through 11 m, in comparison with 3 m in the eastern outcrop where beds lack the finer sediment-sizes. Fig. 3 (9) is composite to the extent that the fossil beds have been shown as 11 m thick though the overall measurements have been taken from the eastern outcrop. As far as can be judged from pacing the sections, the thickness of the upper member is approximately the same in the western and eastern outcrops; the dip is 70°W in the west and 35°W in the east. The junction of lower and upper members is extremely weathered and the boundary is not definite in the west section but from 180-225 m of the lower member are present.

Leeson (1970, pp. 27, 28) described a section across Red Range but did not say where it was measured. Although he also subdivided the Pound Quartzite into three units, the lower two of which are equivalent to the lower member, his thicknesses cannot be reconciled with those of Major. This boundary between lower and upper member (Leeson, in Leeson and Nixon, 1966) occurs in the field precisely where it would be placed on Major's data. Leeson describes the base of the lower member as intertonguing with the Wonoka Formation, and also as being conglomeratic at the north end of Red Range, adjacent to Beltana Diapir. He could not recognize any pebbles from the diapir in his sediments but very little of the diapiric material is of striking lithology.

Threefold sequences like that at Red Range are also found at Randell Lookout in Edicara Range and Mt. Scott Range, and, according to Leeson (1970), are general for the area of the Beltana 1:63,360 map. The sections measured at Randell Lookout by Major (unpublished thesis, 1964) and by Daily (1956) at Mt. Scott

Range are used in Fig. 3 (10, 11). Neither author attempted a major sub-division of the Pound Quartzite. When correlated with each other and with the fossil beds this threefold sequence fits the regional picture, as Leeson (1970) has said, provided the lower two units are correlated with the "lower, red member" of the sections to the south (Fig. 3 (1-8)). The fossil beds thus provide confirmation of the lithologic correlation in this region though elsewhere on the western flank the stratigraphic position has been used to show that the fossil beds form one band only. Leeson (1970, pp. 27, 28) also published a section through the Pound Quartzite at Randell Lookout which is not in close agreement with that of Major except for the overall thickness.

The topographically highest ridges in Red Range and Randell Lookout sections are white sandstones among the red and white sandstones. They replace the white member as the chief scarp-forming ridges here, though not at Mt. James as is clear from Goldring and Curnow (1967). At Mt. Scott Range, in a similar set of three lithologic types, the chief scarp-forming bed is again a white sandstone among the red and white sandstones, and once more the fossil beds occur in maroon sandstones and silts about 60-80 m above the base of the third unit (the dominantly white sandstones). This local variation points to an independent movement involving the Beltana Diapir complex, which preceded the regional shallowing of the deposition basin that terminated deposition of the lower member.

SECTIONS EXAMINED

The Western Flank

The type area of the Pound Quartzite, Wilpena Pound itself, has been investigated near Wilpena Chalet on the east side of the entry (Fig. 3 (4)) but here the bedding planes are often current-swept, and massive to coarsely laminated sandstones form the lower part of the upper member; indeed, it is massive throughout. It is the only section on the west flank where the fine-grained beds which are usually fossiliferous are known to be completely replaced by coarse sediments; though the sediments at Nilpena Hills tend this way, a few clayey laminae were present there. Sections which have been systematically searched for fossils have been plotted on Fig. 2 (1-21) but save for Wilpena Chalet, section 4, unfossiliferous sections are not ilustrated in Fig. 3 for they have not been measured in whole or in part as have those that are illustrated. Two of these unmeasured sections have yielded fossililferous float but nothing *in situ*: 13, Nilpena Hills, 27 km W of Green Well Creek, and 17, Patawarta Gap on the east flank of the Flinders Ranges, 25 km E by N of Green Well Creek. Possibly fossiliferous float was found at 12, Puttapa Spring. At 8, Green Well Creek, and 7, Parachilna Gorge, a more gradational change from lower to upper member is seen than that found to the south. From the commencement of dominantly orthoquartzitic sandstone deposition, it is interlayered with haematitic siltstones and sandstones for the first 4·5 m at Green Well Creek and the first 15 m at Parachilna Gorge. As the fossiliferous beds can be traced from the south to Green Well Creek the rather massive orthoquartzites below the transitional, banded bed there must represent the top of the lower member (Fig. 3 (8)), though they were mapped as belonging to the upper member which is covered by outwash on the north side of the creek. These massive orthoquartzites occur so high in the lower member that they can scarcely represent the sandstones associated with the Beltana Diapir (pp. 93, 94). There are nearer small diapirs (Fig. 2), Nilpena and Greenwell Diapirs being closest and both associated with Nuccaleena Fault (Leeson, 1970). Facies changes between Nuccaleena and Greenwell Faults and adjacent to Greenwell Diapir (Leeson, 1970, fig. 6) show that this diapir was moving in late Lower and Middle Marinoan times, while the recorded movement of Nilpena Diapir was post Lower Cambrian. They outcrop on Nuccaleena Dome, a much larger structure which Leeson (1970) considers likely to overlie a large diapiric core of which they are apophyses.

At Parachilna Gorge some bands of haematitic sandstone are present throughout the lower three-quarters of the upper member; these, and interbedded white sandstones, are both rather sugary in texture and often become friable when weathered. In these last two characters the white sandstones of Green Well Creek and Nilpena Hills are similar. The upper one quarter of the upper member at Parachilna Gorge is as indurated and massive as is usual in the upper member further south, and the lower three-quarters is also massive (except for the fossiliferous beds) only a few km to the south (pers. comm. R. F. Harris).

The fossil beds at Brachina Gorge (Fig. 3 (6); table 1) are the richest part of the new outcrop but otherwise quite typical, and are detailed as an example (Fig. 4A). Total thickness of the lower member here is 340 m, and of the upper member 440 m. The fossiliferous section at Brachina Gorge begins 71 m above the base of the upper member and consists of the beds numbered 3-6 in Fig. 4A: (3) 10 m silty, fine sandstone with minor amounts of clay. Most is maroon but some laminae are slightly greenish white. (4) 3·3 m dense, massive, white sandstone with mud pellets concentrated near the base. To the south of a transverse fault which is hidden by scree except where it intersects Brachina Creek, this white sandstone is less massive, less well exposed, and possibly thinner but is still the only totally unfossiliferous subdivision of the "fossiliferous" beds. (5) 8 m silty, clayey sandstone, maroon coloured, with slump rolls of coarser maroon sandstone in the upper 1 m. (6) At least 3 m dense, massive white sandstone with slump rolls and occasional bedding planes that bear *Dickinsonia* fairly commonly and less often other fossils similarly "resistant" enough (Wade, 1968) not to have collapsed or decayed prior to the setting of the enclosing rock. The same lithology continues above (Fig. 4A (7)) but without fossils, although very rare bedding planes are found with surfaces whose smoothness indicates that the sand forming them was deposited against a fine-grained surface (Wade, 1968). These could preserve fossils but are very rare; their total exposed area is only a few square metres. No fossils are known. This same rarity prevails in the massive beds at every section examined. The cross-stratified to flat-stratified facies of the Pound Quartzite is normally deposited under too rigorous conditions of sediment-transport to preserve a soft-bodied fauna. On some rock faces even smooth surfaces showed evidence of sediment-transport which would have destroyed soft bodies; Wilpena Chalet and Patawarta Gap sections are samples of this—but nevertheless a piece of float with faecal pellets on it was found in the creek at Patawarta Gap.

At Bunyeroo Gorge (Figs. 3 (5), 4B) the fossil beds contain considerable fine-grained white sandstone which is largely barren but has fossiliferous layers intermittently in it. Fine-grained maroon sandstones to siltstones occur higher in the section, and the lower 6 m of coarser sandstones above the fine-grained sediments parts on bedding planes which are occasionally fossiliferous. The beds continue to the south, becoming coarser and unfossiliferous to the SSE in Wilpena Pound. They thicken considerably but remain fossiliferous to the SSW, where the greatest thickness of the fossil beds (112 m) was measured at Mayo Gorge, where Hookina Creek cuts through Elder Range, 15 km N of Hawker. This section is complicated by a number of faults and the lower part of the upper member is repeated four times. The most informative section (Figs. 3 (2), 4C) is in the block between faults F2 and F3. It is rather sparsely fossiliferous except near the top of the lower fossiliferous bed where the epichnial groove Form B is common and medusoids are rare. In the same stratigraphic position between faults F3 and F4 quite a rich fauna was found (Table 1). The base of the section was absent from this block.

The more westerly section at Hells Gate (Fig. 3 (3)) is probably not as poorly fossiliferous as the record of only Form B would suggest. It is deeply weathered and leached white now, though it may have been partly red-beds prior to weathering. It does not part cleanly; its very floury texture indicates that chemically destructible, presumably clayey, material was present throughout the laminated, fine-grained silty sandstone. The Yappala Range section (Figs. 2; 3(1)), on the other hand, is really sparsely fossiliferous. As in Mayo and Bunyeroo Gorges, the fossiliferous beds are largely white, laminated sandstone with some maroon siltstone near the top. The fine-grained beds here are closer to the base of the upper member than in any other section, only 16 m above the lower member.

The section at Black Jack Range (Fig. 2 (21)) may yet prove to be sparsely fossiliferous; a short distance above its base, the upper member contains mainly very fine-grained maroon and white sandstones in a limited exposure. Chace and Druid Ranges to the northeast contain a similar sequence but it is badly weathered and badly exposed at sections 19 and 20, as on Mawson's line of section (1941). As the sequences are traceable into those at Yappala Range and Black Jack Range, respectively, they must be considered as potentially fossiliferous.

The Eastern Flank

There is much less outcrop of Pound Quartzite on this flank. This is partly due to Late Precambrian and early Cambrian erosion and/or non-deposition. The upper member is totally absent in the vicinity of the Oraparinna Diapir, as is the Parachilna Formation. Going northward, first the Parachilna Formation and then the upper member of the Pound Quartzite re-appear and thicken northward (Dalgarno, Johnson and Coats, 1964, 1:63,360 geological map, Blinman sheet). Section 18 at Wirrealpa Hill near Mt. Lyall was examined as it is one of the thickest sections of both members. Apart from some small circular shapes in the lower member which were probably due to mudflakes, no possible fossils were found. The mapped boundary between lower and upper members is not unequivocal in this section, it was placed by Dalgarno and Johnson (1966) at the lower of two positions that seem equally possible. This placement results in some medium to rather fine red and white sandstones being considered as low in the upper member in preference to high in the lower member. No fossils were found.

The Northern Flinders Ranges

Only the southern tip of this broadly V-shaped region was included in the area studied. The only previous record of Precambrian fossils in this area (Sprigg and Wilson, 1953) was of a single fossil jellyfish from 3·3 km ENE of Mt. Uro, in the Pound Quartzite of the NW flank of the Arrowie Basin, NE of Narina Basin (Fig. 2). About 33 km to the SW of this, on the SW side of Narina Basin, Patawarta Gap was investigated. The hill at the south side of the Gap (section 17) and the creek-bed were examined. The upper member is exposed as a series of four large questas of massive to flat-bedded, white sandstone. Exposure is almost total. Surfaces are current-swept or ripple-marked and fine sediments are lacking. The lithology most closely resembles the upper member in the Wilpena Chalet section where sediments also may have the winnowed appearance that results from medium to coarse sandstones, individually well-sorted. The underlying red, lower member consists of finer sandstones to siltstones and does not outcrop very well. It was not completely traversed. A sharp-edged piece of float bearing faecal pellets was found in the creek; this is a greyish sandstone with maroon surfaces like the haematite-coated flags from the lower fossil beds at Ediacara (Wade, 1968). In lithology it more closely resembled the lower member than the upper but it was less battered than float which had travelled 1 km down the creek from the upper member. Lateral transport from between two questas is suspected. This section is east and a little north of Green Well Creek, across an axial high with small exposures of diapirs. The most northerly fossiliferous occurrence known is the section 1·5 km E of Mt. Scott (Fig. 3 (11)). It has been discussed together with the correlation of other sections in the vicinity of Beltana Diapir (pp. 93, 94). Section 12 east of Puttapa Spring is also similar; it yielded doubtfully fossiliferous float though no fossils were found *in situ* there.

The syncline extending east from Patsy Springs Homestead past Angepena Homestead was investigated in two sections that proved to be ill-chosen (15, 16). The north limb, just south of Angepena Homestead, is overturned. It contains silty and clayey beds but these are somewhat deformed; sandstones among them are massive, and there is a general lack of flaggy sediments. They do not resemble the Mt. Scott section. The south limb, near Mt. Wallace, is a much thicker section of fine to dominantly medium and coarse sandstones with some pebble bands. The preliminary Copley 1:250,000 sheet shows it as a fault trough associated with the Mucatoona Diapir to the east and south. This diapir was apparently shedding sediment into the area during the time of deposition of the Pound Quartzite. Coats (1964b) described evidence of instability at the Patsy Springs end of the syncline just prior to the deposition of the Wonoka Formation.

The northernmost section studied (14) was that at Mundy Waters east of Leigh Creek, near Mt. Telford and just north of Boolooroo Diapir. Neither fossils nor fine-grained beds were found there. There was no clear-cut division into two or even three members. Sandstones tended to reddish and roughly flaggy in the higher beds and greyish and more massive in lower beds which were not continuously exposed.

OVERLYING SEDIMENTS

Parachilna Formation

In the Northern Flinders Ranges, both in the Angepena syncline and the Mundy Waters syncline, drab, olive-green siltstones with minor sandstones underlie the sandy facies of the "worm burrow beds" with *Diplocraterion* and other burrows. In the Mundy Waters section, above the drab, olive-green siltstones and interbedded barren, grey sandstones, the form Glaessner (1969) considered probably *Rusophycus* Seilacher is a common fossil in sandstones crowded with less characteristic trails. The facies and fauna is closely similar to that from near the top of the Arumbera Formation (Glaessner, 1969) and may similarly be lowest Cambrian in age. *Plagiogmus* Roedel has also been recorded in this formation by Glaessner (1969), and Daily, Twidale and Alley (1969) who listed it from sections overlying the Pound Quartzite at Wilpena Pound. This not only reinforces the resemblance to the top of the Arumbera Formation where it also occurs (Ross River area, east of Alice Springs) but refines the Cambrian dating suggested by the probable *Rusophycus* by correlation with the Swedish occurrance (pers. comm. Martinsson, *in* Glaessner, 1969) which was probably from the Lower Cambrian of Kalmarsund region.

In the Angepena syncline the drab, olive-green sediments are thicker than at Mundy Waters and contain some beds of dark grey, impure sandstones that are crowded with "worm casts" of various sizes and a bifid trail resembling that figured by Glaessner (1969, 9B, C). Most of the trails, however, are simple, unbranched and horizontal. Above them are cleaner sandstones typical of the *Diplocraterion* facies which contain some beds of remarkably deep burrows; they reach 0·6 m deep. Shales again predominate in the beds above the clean sandstones. The olive-green siltstones and sandstones were only observed in these two Northern Flinders synclines, where they appear conformable with the more widespread *Diplocraterion* facies of the Parachilna Formation and to have been included in this formation by Dalgarno (1964) who mentions its "mappable contact" with the Pound Quartzite in this area. If we assume (Dalgarno, 1962; 1964) that the widespread occurrence of thick beds of the *Diplocraterion* sandstone facies is everywhere the same age, then the Parachilna transgression must have started earlier in the Northern Flinders. The total thickness varies from tens of cm to nearly 50 m in the southern area but increases to 370 m in the Arrowie syncline, SE of Angepena syncline (Dalgarno, 1964; Horwitz, 1962). The Parachilna Formation everywhere underlies the Wilkawillina Limestone (or the correlative Ajax Limestone, Daily, 1956; Dalgarno, 1964; Walter, 1967) and wherever investigated has above it a mid Lower Cambrian datum of relatively low in the Upper Aldan Stage. This datum was obtained by Walter (1967) from Archaeocyatha from the middle of the Wilkawillina Limestone. The base of the Wilkawillina Limestone is generally algal limestone and unzoned. From its stratigraphic position we have no cause to suspect a great age range within the Parachilna Formation which is probably all low Lower Cambrian.

OCCURRENCE OF EDIACARA FAUNA

The Ediacara fauna is thus separated from the Low Cambrian by the time taken to deposit 600 m (or more) of Pound Quartzite, a major erosional interval, and the time occupied by a (?mildly) diachronic transgression. The duration of these events is open to many interpretations. Probably our best method of dating the Ediacara fauna is through the gradually improving correlation with related faunal elements that have been dated overseas. This (Glaessner, 1966) currently gives an age around 600-700 m.y. It thus obliquely supports correlation of the Kimberley and Sturtian to Marinoan glaciations.

The known faunal content of the rocks is expanded by every collecting trip. To date, every single fossil is of a form known from Ediacara Range. The present count of species is listed under the section numbers of the localities in Table 1.

TECTONIC SETTING OF SEDIMENTATION

The distribution of the lower and upper members of the Pound Quartzite is not shown on the preliminary Copley 1:250,000 map but older map legends show it is recognizable over much of the area. The Cadnia 1:63,360 sheet (Grasso, Brock and Horwitz, 1960) mentions the reddish colour and shaley interbeds of the lower part. Sprigg and Wilson (1953) were even more explicit on the Angepena sheet (adjoining Cadnia on the north side): "Sandstone and quartzite slightly arkosic in part; principally light-coloured but thick reddish basal development particularly in the south westerly areas." The southwesterly area is part of the nose of the Mt. Scott Range syncline and the description indicates that the two members are no less distinct here than in sections 11 and 12 near Mt. Scott and Puttapa Spring; they may well be more distinctive, being further from the Beltana Diapir complex and the associated orthoquartzitic beds in the lower member (pp. 94).

Thompson (1969b) does not discuss the Pound Quartzite individually but figures it (fig. 27) as a coarser stipple overlying a finer one, both increasing in thickness to represent about 1,200 m of sediment each in the extreme north of Northern Flinders Ranges. This great increase in thickness implies differential tectonic movements over a long time and indicates that the shallowing and the supply of coarser sediments that resulted in the upper member of the Pound

TABLE 1

The known components of the Ediacara fauna and the areas from which they have been collected. Section numbers refer to Fig. 2. The entire fauna from Ediacara Range has been listed under section 10 for convenience. *"*Kimberia*" Glaessner and Wade, 1966, not *Kimberia* Cotton and Woods, 1935.

Section No.	1	2	3	5	6	7	8	9	10	11	12	13	17
body fossils:													
coarse, spicular impressions								x	x	x			
indeterminate medusoids		x		x	x	x		x	x	x	?		
Ediacaria flindersi Sprigg		cf		x	cf	x		x	x				
Beltanella gilesi Sprigg									x				
Medusinites asteroides (Sprigg)									x				
Cyclomedusa davidi Sprigg					x			x	x				
C. radiata Sprigg									x				
C. plana Glaessner & Wade									x				
"*C.*" sp.		x							x				
Mawsonites spriggi G. & W.									x				
Conomedusites lobatus G. & W.					x				x				
**Kimberia quadrata* G. & W.									x				
Rugoconites enigmaticus G. & W.					x				x				
medusoid, n. sp.				x	x				cf				
medusa, n. sp.					x				x				
Lorenzinites rarus G. & W.									x				
Ovatoscutum concentricum G. & W.					x				x				
Chondrophore, n. gen., n. sp.									x				
Rangea longa G. & W.									x				
R. grandis G. & W.									x				
Pteridinium simplex (Gürich)					cf				x				
Arborea arborea (Glaessner)					x				x			cf	
Dickinsonia costata Sprigg		x			x			x	x	x			
D. elongata G. & W.		x			x				x	x			
D. tenuis G. & W.					x				x				
Spriggina floundersi Glaessner					x				x				
Spriggina? ovata G. & W.		x			x				x				
Praecambridium sigillum G. & W.									x				
Parvancorina minchami Glaessner					x				x				
Tribachidium heraldicum Glaessner		x			x				x				
trace fossils:													
Pseudorhizostomites howchini Sprigg		x			x			x	x	x			
Form A (Glaessner, 1969)					x				x				cf
Form B (Glaessner, 1969)		x	x	x	x	x	x	x	x	x			
Form C (Glaessner, 1969)									x				
Form D (Glaessner, 1969)									x		?		
Form E (Glaessner, 1969)		x							x				
Form F (Glaessner, 1969)					x				x				
3-point imprints (undescribed)					x			x	x				
+ ve trail (undescribed)	x	x							x				

Quartzite, are more probably the result of increased tectonism than some eustatic process. Glacial eustatic processes are most unlikely for the geologic instant was long after the deposition of the partly glacial Lower Marinoan Elatina Formation and the Middle Marinoan expansion of sedimentation which Thompson (1969b) suggested could be explained this way.

The six sections studied in the Northern Flinders Ranges (fig. 2 (11, 12, 14-17)) show more variability during Pound Quartzite sedimentation than is recorded in the Southern and Central Flinders ranges but 11 and 12 were associated in documented movements of Beltana Diapir, 15 and 16 with partly documented movements of Mucatoona Diapir, and 14 is very close to Boolooroo Diapir though only post-Lower Cambrian movements are yet documented for that. Only Patawarta Gap (17) seems to have been in a stable area, and to differ from the southern and western sections only in its greater thickness.

The conclusion that the northern area was more actively subsiding than the southern is inescapeable but the roles played by diapirism may appear more strongly differentiated than they actually were. Deep erosion in the axial region of the Central and Southern Flinders Ranges has removed the Cambrian and Upper Marinoan from the neighbourhood of a number of diapirs, and thus reveals more evidence of early movements of the diapirs there, and records less of their later movements. The less deeply eroded areas show more evidence of the younger movements while the older rocks are covered.

Shortly after the onset of coarser (upper member) sedimentation, an elongate deposit of fine sands with minor silts to clays formed (Fig. 3) west of what is now an axial high extending south from latitude 30°45′. The only definitive edge to the fine sediments is found at Wilpena Pound where massive sandstones like those at Patawarta Gap are in line with a low in the axial structure as at present expressed—a gap between two diapirs that had commenced movement by the Sturtian (Dalgarno and Johnson, 1966). The more northerly of these continued its movements intermittently into the Cambrian (Oraparinna Diapir, Dalgarno, 1964; Walter, 1967). No post-Sturtian rocks are associated with the more southerly. All of the larger diapirs on this axis have histories of movement dating back to the Sturtian, except Beltana Diapir which is surrounded by Middle and Upper Marinoan rocks to both of which it contributed coarser sediments. The observations of Coats (1964a) and Dalgarno (1964) on the extent of the movements receive additional documentation from the maps of Dalgarno and Johnson (1966) and Leeson and Nixon (1966) and from Leeson (1970). After the short, and variously interrupted, period of deposition of fine sediments the area returned to the deposition of coarse- to medium-grained, white sands, strongly cross-bedded and ripple-marked, and with intermittent slump rolls—the cross-stratified to flat-stratified facies of Goldring and Curnow (1967).

Alternative explanations for this distribution of fine sediments must take decreasing effect of water movement into account. This could have been caused either by the deepening of the water column over the region of the present Mt. Scott syncline, west flank area and Chace and Druid syncline, or by the formation of barriers reducing wave action. Though in this region only the Beltana Diapir shed boulders into the Pound Quartzite—and that earlier than the widespread change of sedimentary pattern in the south—it hardly seems possible that a general shallowing could affect the basin without re-activating at least some of the pre-existent diapirs. Frome Diapir, east of Mt. Lyall, was eroded at this time (Coats, 1964a). The formation of sheltered areas of sea floor on the landward (west) side of shoals in the general position of re-activated, known diapirs seems the most likely explanation of the short-lived deposition of fine sediments in this shallow sea. Erosion in the axial region has proceeded to a depth that has removed most evidence but statistical work may show maxima in the direction of movement of slump rolls, for instance, which would show the direction of the high or highs that shed them. At Parachilna Gorge they even occurred intermittently during the deposition of the fine sediments.

OUTLYING OCCURRENCES

Two single specimens, each of a pennatulid on a loose rock slab, have been found beyond the confines of the Adelaide Geosyncline (Text-fig. 1; x, y). *Arborea arborea* (Glaessner) was found at locality x, 27°45′, 130°30′, in the uppermost Precambrian Punkerri Sandstone which is correlated with the Pound

Quartzite but not well exposed (pers. comm., R. B. Major). *Rangea* cf. *longa* Glaessner and Wade was found at locality y, east of Deep Well Homestead, 80 km SSE of Alice Springs), in the lower part of the Arumbera Sandstone (Glaessner, 1969). The specimen is identical with Ediacara specimens lacking preserved secondary branches (anthosteles); these have similarly been called *Rangea* cf. *longa*.

The Arumbera Sandstone is Lower Cambrian at its top (Glaessner, 1969) and is conformable with the Precambrian Pertatataka Formation (Wells, *et al.* 1967; Forman and Milligan, 1967, maps only, pls. 10-13). These authors provisionally considered the entire formation Cambrian though Wells *et al.* noted that the base could be Precambrian. The known fauna consists mostly of the trails and burrows described by Glaessner (1969) mainly from a bed about three-quarters the distance from bottom to top of the formation, and higher. (The existence of two published variants of the thickness in the Laura Creek region, 23 km WSW of Alice Springs, 600 m and 430 m, leads me to prefer to render the relative positions as ratios). The commonest trace fossil, by field observation, is a small diameter, unnamed burrow filling (Glaessner, 1969, fig. 6E) which also may occur in the finer sediments right down to (but not in) the lowest ridge-forming sandstone a little less than one quarter the distance from base to top. About two-thirds of the distance from the base to top the well-preserved but undescribed medsoid collected by G. K. Williams was obtained (Glaessner, 1969; G. K. Williams, pers. com.); one specimen of an epichnial groove inseparable from Glaessner's Form B in the Ediacara fauna was collected half way through the formation, and a few *Hallidaya brueri* Wade from one quarter the distance from base to top (Wade, 1969). The *Rangea* from Deep Well was said to be from near the base of the Arumbera sandstone.

The known fauna may be summarized as: one form known from the Ediacara fauna from near the base, 2 medusoids not known from the Ediacara fauna and 2 trace fossils with overlapping ranges, one previously known from the Ediacara fauna and one from the Cambrian, from the central part of the formation, and several Cambrian trace fossils from the upper quarter. Thus whether we accept the evidence of bridging of the Cambrian to Precambrian boundary or not, we have elements of a fauna which must represent at least the upper part of the time unrecorded in the Adelaide Geosyncline, due to the unconformity between the Pound Quartzite and Parachilna Formation.

Webby (1970) has comprehensively described the lately-discovered trace fossil faunas of the Fowlers Gap Beds and the Lintiss Vale Beds in north-west New South Wales (Fig. 1z). It is unfortunate that not many of his forms are very distinctive but most satisfactory to have a description of the complete fauna.

Webby noted that about 3 times as many kinds of activity were present in the upper fauna (from the Lintiss Vale Beds) as in the lower (Fowlers Gap Beds) fauna. He pointed out that the same conclusion could be derived from his material as from literature, that the trace fossil faunas become richer as the Cambrian is approached. Glaessner (1969) came to the same conclusion from comparison of literature, the Precambrian Ediacara fauna trace fossils and the definitely low Lower Cambrian Arumbera Sandstone fauna. Webby based his decision that he was dealing with a Precambrian fauna on the absence of Arthropod markings and most complex burrows, though he noted some typically Cambrian forms, a new *Phycodes*? and bilobed and trilobed trails in his upper fauna. His Fig. 11 could be a fragment of *Plagiogmus* which is sometimes preserved as a burrow filling but even disregarding this possibility there are close resemblances between the Parachilna-Arumbera fauna and the Lintiss Vale fauna. *Phycodes*? *antecedens* Webby is admittedly close to *Phycodes pedum* Seilacher which occurs in the Arumbera and possibly is also present in the Parachilna Formation at Mundy Waters. The bilobed trail (Webby, 1970, Fig. 12A,B) appears identical with the Parachilna Formation form figured by Glaessner (1969, Fig. 9B, C). *Planolites ballandus* Webby (1970, Fig. 14A, C) can be duplicated from the Arumbera Sandstone. *Gordia* sp. of Glaessner (1969, Fig. 9E) is an external mould identical in shape and size to *Cochlichnus serpens* Webby. Small, curved trails differing from *Torrowangea rosei* Webby by the pellets being less closely packed and the curves smoother and more open, occur below the richly fossiliferous sandstone three-quarters the distance from bottom to top of the Arumbera Sandstone.

The aspect of the Lintiss Vale trace fossil fauna is more like the low Lower Cambrian fauna than the Ediacaran. If further collecting fails to produce more of the Cambrian element in the fauna, its age will have to be considered intermediate between the low, Lower Cambrian and the Ediacara fauna. The Ediacara fauna must be re-sought below the Lintiss Vale Beds. The Fowlers Gap fauna would not appear out of place in the Ediacaran but is too poor to date.

CONCLUSIONS

The long-awaited evidence on the stratigraphic placement of the Ediacara fauna has been provided by a band of fossiliferous rocks near the base of the upper member of the Pound Quartzite. This so closely parallels the boundary between the lower and upper members as to entitle us to regard this boundary as a time plane through the western side of the Flinders Ranges. It also highlights the tremendous amount of erosion that took place on the locally inconspicuous unconformity between Pound Quartzite and Parachilna Formation. The thinning of the lower member at Ediacara Range has to be regarded as a depositional thinning since both the typical "lower member" beds and the "red and white sandstones" above them are thinned in the same proportions relative to the Mt. Scott and Red Range sections. The upper member could owe its thinning here only to erosion (Fig. 3 (10)) as the beds below the fossils are of average thickness, but erosion has removed the evidence.

Evidence of repeated movement on the diapiric cores from Sturtian to post Lower Cambrian continues to mount. It appears clearer that the major stratigraphic highs seen in the zone of diapirism today have been highs repeatedly since the Sturtian and were not re-elevated by chance in the lower Palaeozoic folding of the geosyncline.

The discovery that a low Lower Cambrian fauna in the upper quarter of the Arumbera Sandstone is correlatable to the Parachilna Formation (Glaessner, 1969) reveals the fact that the differing fauna in the middle of the Arumbera Sandstone represents a zone above the Ediacara fauna. Whether this should be assigned to the Cambrian or the Precambrian will await inter-regional correlation. The discovery of a fauna of about this age near the top of a continuous sequence in northwest New South Wales (Webby, 1970) gives a second possibility of establishing the Precambrian-Cambrian boundary in a continuously zoned succession, as has been done with later era boundaries. This area may provide a suitable subsiduary section for the top of the Upper Marinoan.

ACKNOWLEDGMENTS

Part of the field work was supported by an Australian Research Grant to Professor M. F. Glaessner, and part by the University of Adelaide. I have had the benefit of numerous discussions with Professor Glaessner during the course of this work, and his criticism. A number of people have assisted with the field work at various times; the assistance of Mr. J. C. Gehling has been outstanding.

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